



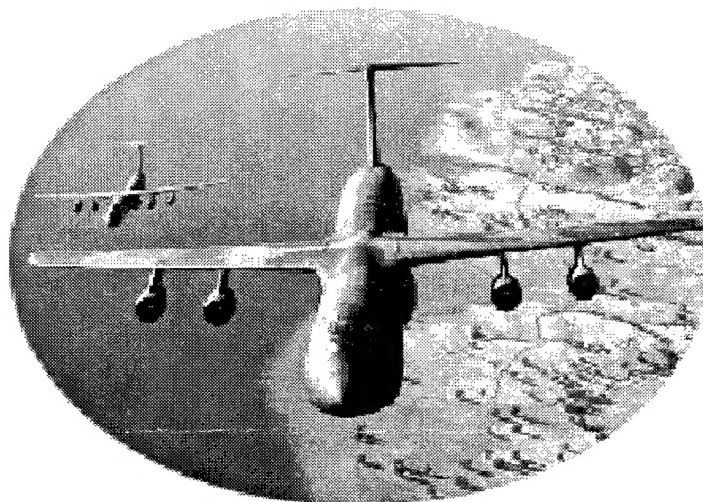
USAFA Discovery is published quarterly by the faculty of the US Air Force Academy (USAFA). It contains reports on USAFA cadet and faculty research, a complete list of current USAFA research points of contact, and a summary of recent awards and publications. All written material contained within reflects the opinions of the authors and editors and does not necessarily reflect current US Air Force or USAFA policy.

BONDED REPAIRS FOR THE UNITED STATES AIR FORCE'S FLEET OF AGING AIRCRAFT *THE EFFECT OF PRE-LOADING ON THE PERFORMANCE OF BONDED REPAIRS*

The Center for Aircraft Structural Life Extension, CASTLE, is one of the seven research centers at the United States Air Force Academy and has been conducting research in the field of aging aircraft over the past 6 years. The U.S. Air Force operates the largest fleet of aging aircraft in the world and the center's research supports the structural maintenance related to operating these aircraft. The center is mainly focusing on the application of bonded repairs, using state-of-the-art composite materials such as Glare (a fiber-metal laminate made of alternating layers of aluminum and fiberglass) and boron-epoxy composite as repair materials, and high-temperature curing adhesives.

CASTLE is currently working on several projects, both basic research and projects with more near-term applications. The project highlighted in this article focuses on the effect of static loads that can already be present in an aircraft structure while it is being repaired. When applying a bonded repair to a fatigue crack on a pre-loaded structure, these loads are "captured" in the repair after the adhesive has cured, and it is believed that these loads can have a large influence, either beneficial (for compressive loads) or not (for tensile loads), on fatigue crack growth after application of the repair, since they are additional to the operational loads that act on the aircraft.

A good example of a structure that is pre-loaded in tension during the application of repair patches is the aft-crown section (the top of the fuselage) of the C-5A Galaxy. Perhaps surprisingly, the cracks in this section of the aircraft are not caused by flight loads, but by the sheer weight of the large tail section when the aircraft is parked. These same loads that are causing the cracks are present in the structure while it is being repaired. Another example, where compressive loads play a role during patching, is that of the lower wing skin panels of the C-141 Starlifter. Teardown inspections of these aircraft showed evidence of widespread fatigue damage



The C-5A (foreground) and C-141 (background) are two aging aircraft using bonded repair technology.

in the fuel drain holes in the integral stiffeners in the lower wing skins. Due to the load of the wing itself and of the engines, the lower wing skin is in compression while on the ground. Patching the skin and stiffeners under these conditions can add beneficial compressive stresses on the crack, which will cause it to grow more slowly. A better understanding of the effects of these loads could lead to the decision to change the pre-load in the structure by, for example, jacking up the tail section of the C-5A and so relieving the tensile stresses during the cure. In the case of the C-141, perhaps prohibiting patches from being bonded to the lower wing skin while the engines have been removed for maintenance (and the favorable compressive stresses are reduced) would be desirable.

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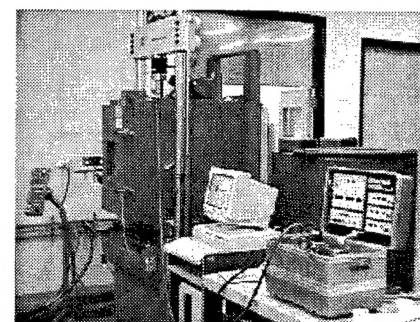
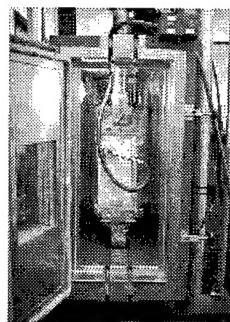
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To simulate the worst-case scenario in the lab, cracks in 1.0 mm thick aluminum panels were repaired while the panels were in tension. Both boron-epoxy and Glare patches were used and the panels were pre-loaded at two different stress levels: 60 and 120 MPa. Panels without a pre-load were also tested as a reference. In order to apply the repairs while the test panels are in tension, the set-up is somewhat more complex than for the standard repair test specimen. The panels are pre-loaded in a tensile machine while a thermal chamber is fitted around the tensile machine to heat up the panels to the required 250°F to allow the adhesive to cure. The photos top right show a panel in the tensile machine while the thermal chamber is fitted around the setup. A vacuum bag on the panel is used to evacuate all air so that pressure is applied to the bond line between the patch and the panel.

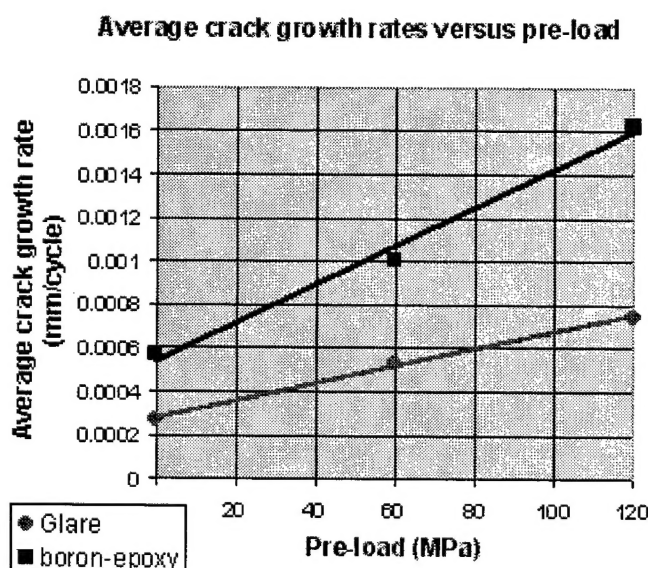
After the patches were bonded to the panels, the specimens were tested in fatigue under constant amplitude loading with a maximum stress of 120 MPa and a minimum stress of 6 MPa to compare the performance of the repairs with the different pre-loads.

It was found that the pre-loads have significant effects on the performance of the repairs. The graph below right shows the average crack growth versus the pre-load for specimens with boron-epoxy and Glare repairs. As can be seen, the influence of the pre-load is very significant, and a pre-load of 120 MPa almost tripled the crack growth rate compared to the no-pre-load case. It was also found that the influence of the pre-load is larger for the specimens repaired with boron-epoxy patches, which is due to the greater difference in thermal properties between boron-epoxy and aluminum versus Glare and aluminum.

Work is currently being done in analyzing the results and modeling the effects of the pre-loads on patch performance so that effects of pre-loads can be predicted for repairs to real aircraft structures. These results, along with the results of future tests, will be used as part of a comprehensive approach to extending the lives of USAF aging aircraft. By understanding the effects of pre-loads on bonded repairs, more effective repairs can be made, leading to economical aircraft life-extension.



A patch is being bonded to an aluminum panel while the specimen is in tension.



Department Research News

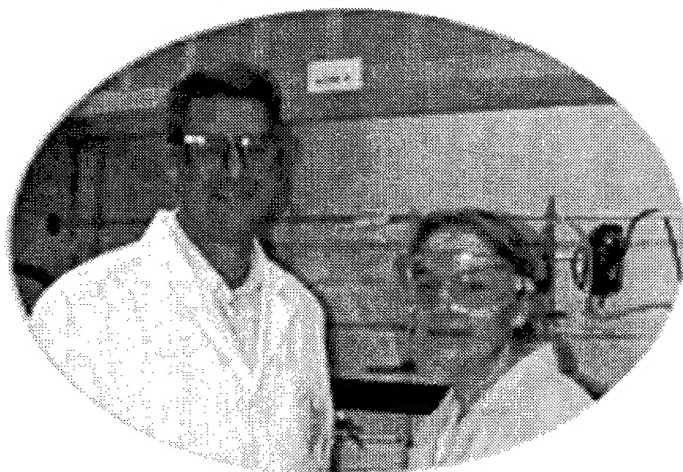
Department of Behavioral Sciences and Leadership

THE 1999-2000 RHR INTERNATIONAL OUTSTANDING DOCTORAL DISSERTATION AWARD

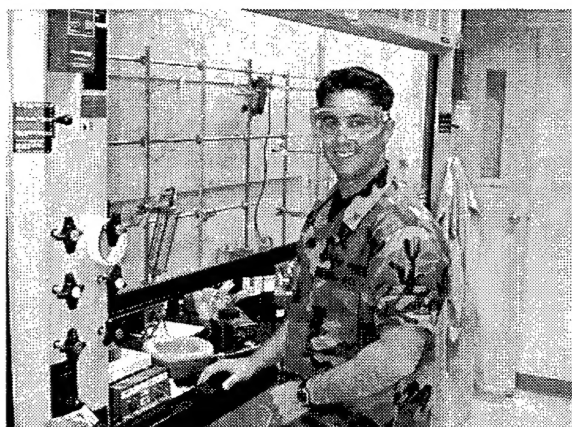
The Consulting Psychology Division of the American Psychological Association awarded the 1999-2000 RHR International Outstanding Doctoral Dissertation Award to Lt Col Tanoff of DFBL. The award included \$1000 and an invitation to present his research at the 2001 Annual American Psychological Association Conference in San Francisco. The dissertation was titled, "The Utility of the Five Factor Model of Personality." Lt Col Tanoff completed his dissertation at the University of Oregon in March of 1999.

Department of Chemistry

Cadets in the Chemistry Department under the direction of Major Mace Golden are investigating the use of a DNA-based analytical method, which can bind with high specificity and sensitivity analyte molecules.



Major Mace Golden and C2C Mary Cunningham



C2C Rob McGill

Department of Astronautics

Small Satellite Program

C1C Stuart Stanton (representing the Department of Astronautics) presented the proposed Charging Hazard and Wake Studies-Long Duration (CHAWS-LD) and Miniature Electrostatic Analyzer (MESA) payloads to the AF Space Experiments Review Board (SERB) in August.

In essence, they are using DNA outside the body like the immune system uses protein-based combinatorial systems within the body. This begins by generating a staggering number of possible solutions to a binding problem using a solid-phase DNA synthesizer. The size of this 'library' (and the size of the number of different DNA molecules) depends on the length of the random region of the various single stranded DNA molecules—called aptamers. The trick is to then isolate those very few aptamers with the desired properties from all the others in the original library by gel partitioning and polymerase chain reaction amplification.

A new spin to this process is to modify the bases (the individual molecular subunits) which make up the DNA molecules. C2C Mary Cunningham is currently synthesizing a modified uridine molecule, which can form a strong bond to protein targets when excited by UV or even visible light. This is done by including special light-absorbing units called chromophores at key locations on the base, which absorb light but do not inhibit enzymatic replication. This technology may revolutionize diagnostic science and permit the ready determination of many different types of ailments from a single, small sample of patient serum. C2C Rob McGill is taking this technology one step further. He is synthesizing a uridine base, which can form an amide bond to a target protein in an aqueous environment. If he can get sufficient specificity, this technology may be used to shut down proteins which supply growing cancers with a blood supply and thereby halt them.

Department of Behavioral Sciences and Leadership

LCDR Russell Shilling completed a certification course for designing and building THX theater systems offered by the THX Division of Lucasfilm in San Rafael, CA. This course is directly applicable to his ongoing research in auditory displays in virtual environments. While there, he initiated contacts that will allow him to tap into the expertise of the film industry to improve audio systems in simulations and VE. LCDR Shilling will be departing USAFA in December for a teaching assignment at the Naval Postgraduate School where he will be dual-hatted in Operations Research and the Modeling, Virtual Environments, and Simulation (MOVES) program. He has received a \$72k research grant for developing an efficient audiometric test of sound localization ability and \$20k for designing a high-end audio system for a virtual environments testbed. LCDR Shilling would like to continue contacts and collaboration at USAFA.

Publications and Presentations

34th Education Group

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Department of Aeronautics

Publications:

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Department of Astronautics

Publications:

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Presentations:

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LEE, K. "Modeling and Analysis of Launch Vehicle Thermal Protective System (TPS) Concepts." AIAA Student Conference, Wichita, Kansas, April 2000.

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ASTORE, W., History of Technology Conference, Leeds, UK, April 2000.

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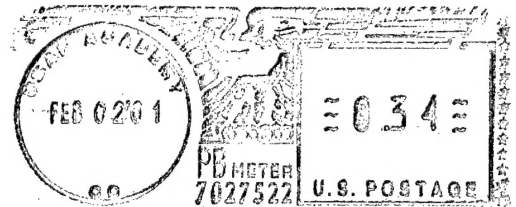
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